Secondary Charmonium Production in Heavy Ion Collisions at LHC Energy

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We consider the production of charmonium by $D\bar{D}$ annihilation during the mixed and hadronic phase of a Pb-Pb collision at LHC energy. The calculations for secondary J/ψ and ψ' production are performed within a kinetic model taking into account the space-time evolution of a longitudinally and transversely expanding medium. It is shown that the yield of secondary J/ψ mesons depends strongly on the J/ψ dissociation cross section with co-moving hadrons. Within the most likely scenario for the dissociation cross section it will be negligible. The secondary production of ψ' mesons, however, due to their large cross section above the threshold, can substantially exceed the primary yield.

1. Secondary charmonium production

The initial energy density in ultrarelativistic heavy ion collisions at LHC energy exceeds by a few order of magnitudes the critical value required for quark-gluon plasma formation. Thus, according to Matsui and Satz [1], one expects the formation of charmonium bound states to be severely supressed due to Debye screening. The initially produced $c\bar{c}$ pairs in hard parton scattering, however, due to charm conservation, will survive in the deconfined medium until the system reaches the critical temperature where the charm quarks hadronize forming predominatly D and $\bar{D}$ mesons. The appreciable number of $c\bar{c}$ pairs and consequently D,$\bar{D}$ mesons expected in Pb-Pb collisions at LHC energy can lead to additional production of charmonium bound states due to the reactions such as, $D\bar{D}^* + D^*\bar{D} + D^*\bar{D}^* \to \psi + \pi$ and $D^*\bar{D}^* + D\bar{D} \to \psi + \rho$ as first indicated in [2]. In this work we present a quantitative description of secondary J/ψ and ψ' production due to the above processes from the thermal hadronic medium created in Pb-Pb collisions at LHC energy.

2. Cross section and production rate

The charmonium production cross section $\sigma_{D\bar{D}\to\psi h}$ can be related to the hadronic absorption of charmonium $\sigma_{\psi h\to D\bar{D}}$, through detailed balance. The magnitude of charmonium absorption cross section on hadrons is still, however, theoretically not well under control. In fig.1 we show the predictions for the dissociation cross section of J/ψ on

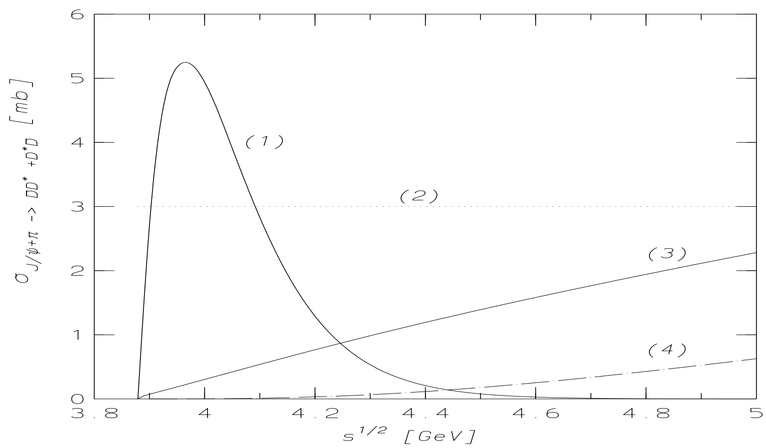

Figure 1. Energy dependence of the J/ψ absorption on pions predicted in the contex of four different models (see text for description).

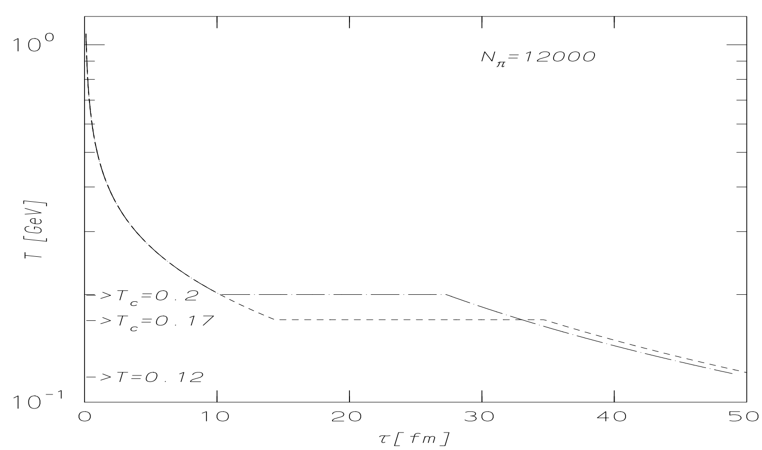

Figure 2. Model for space-time evolution of the hot medium created in Pb-Pb collisions at LHC energy.

pions of: (1) the quark exchange model [3], (2) the comover model with $\sigma_{\psi\pi}$ ~3mb [4], (3) calculations using an effective hadronic Lagrangian [5] and (4) a short distance QCD approach [6]. The large theoretical uncertainties of the cross section seen in fig.1 will naturally influence the yield of secondary charmonium bound states.

In the thermal hadronic medium the rate of charmonium production from $D\bar{D}$ annihilation is determined by the thermal average of the cross section and the densities of incoming and outgoing particles [2]. The solution of the rate equation requires additional assumptions on the space-time evolution of the hadronic medium and the initial number of D and $\bar{D}$ mesons at the beginning of the mixed phase.

We have adopted a hydrodynamical model for expansion dynamics assuming that at initial time $\tau_0 \sim$ 0.1fm the system is created as an equilibrium quark-gluon plasma of temperature $T_0 \sim$ 1GeV and is then undergoing isentropic longitudinal expansion with a superimposed transverse flow. In fig.2 we show the time evolution of the temperature in

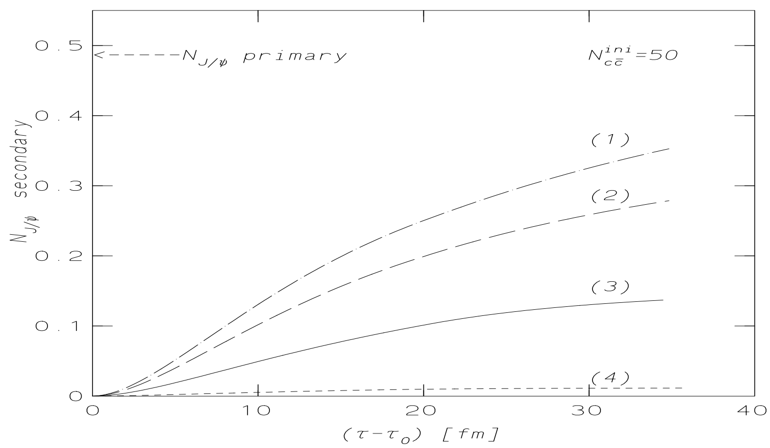

Figure 3. Time evolution of the abundance of secondarily produced J/ψ mesons from Pb-Pb collisions at LHC calculated with the cross sections from fig.1.

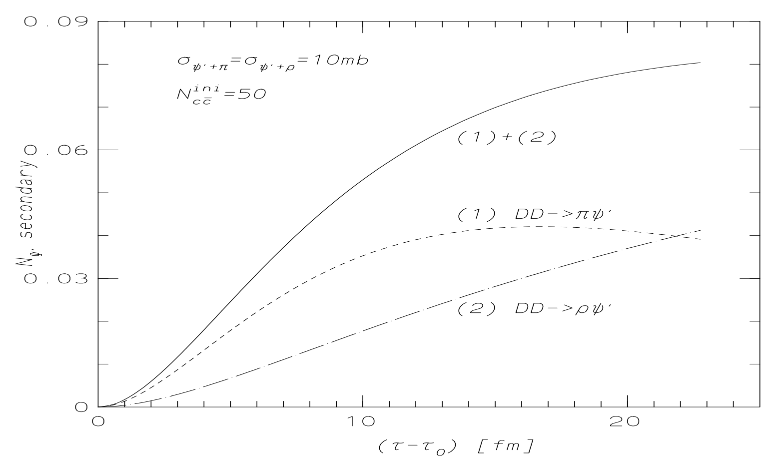

Figure 4. Time evolution of the abundance of ψ' from Pb-Pb collisions at LHC calculated with constant absorption cross section, $\sigma_{\psi'\pi} \sim \sigma_{\Psi'\rho} \sim$ 10mb.

our model for two values of T_c with 12000 pions (charged and neutral)per unit of rapidity in the final state. In the actual numerical calculation we take $T_c \sim$ 0.17GeV as value for the critical temperature, following recent calculations within the lattice gauge theory approach [7]. The analysis of presently available data for the yield of hadrons produced in heavy ion collisions suggests that the chemical freezeout temperature at LHC should be in the range $0.16 < T_f < 0.17$ [8,9], i.e very close to T_c.

To get the initial number of $c\bar{c}$ pairs in Au-Au collisions at LHC we scale the $p-p$ calculations from PYTHIA with the total number of nucleon-nucleon collisions [10]. Typical rapidity densities of 50 $c\bar{c}$ pairs were obtained, leading to about 50 D and $\bar{D}$ mesons and 0.5 primary J/ψ at midrapidity.

In fig.3 we show the time evolution of the abundance of J/ψ mesons as obtained from the solution of the kinetic equations with four different values of the J/ψ absorption cross section as described in fig.1. As is seen in fig.3 the yield is very sensitive to the size of the

absorption cross section. For example, using the short distance QCD approach leads to negligible secondary production of J/ψ mesons. Similar analysis for ψ' is shown in fig.4. Here, due to the small binding energy of the ψ' meson and its correspondingly larger size, we have taken the cross section for ψ' absorption by pions and rho mesons to be energy independent and equal to its geometric value of 10 mb just at threshold [11]. The results in fig.4 show that the secondary yield of ψ' can be large and reaches the value of almost 1/5 of the initial number of primary J/ψ. The yield is also seen to be very weakly dependent on the freezeout time.

Thermal $c\bar{c}$ pairs produced during the evolution of quark-gluon plasma are, within our approach, found to increase the secondary charmonium yield shown in fig's.3,4 by 40% with an equilibrium initial conditions as used in fig.2 and by 20% if using the initial conditions from SSPC [12] for a plasma out of chemical equilibrium.

A detailed presentation of the results can be found in [13].

3. Conclusions

We have shown that secondary charmonium production in heavy ion collisions appears almost entirely during the mixed phase. The yield of secondarily produced J/ψ mesons is very sensitive to the hadronic absorption cross section. Within the context of the short distance QCD approach this leads to negligible values for J/Ψ regeneration. The ψ' production, however, can be large and may even exceed the initial yield from primary hard scattering. It is thus conceivable that at LHC energy the ψ' charmonium state can be seen in the final state whereas J/ψ production can be entirely suppressed.

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